Newtonian Airless Liquid Jet Interaction with a High Speed Moving Surface

B. Keshavarz[1], S.I. Green, M.H. Davy, and D.T. Eadie
Department of Mechanical Engineering, University of British Columbia
Vancouver, BC, V6T1Z4, Canada

Abstract

In the railroad industry a friction modifying agent may be applied to the track in the form of a liquid jet. In this mode of application the interaction between the high speed liquid jet and a fast moving surface is important. Seven different Newtonian liquids with dissimilar shear viscosities were tested to isolate the effect of viscosity from other fluid property effects. High speed video imaging was employed to scrutinize the interaction between the impacting jet and the moving surface. Decreasing the Reynolds number reduced the incidence of splash and consequently enhanced the transfer efficiency. The Weber number had a smaller impact on splash than did the Reynolds number. The ratio of the surface velocity to the jet velocity has only a small effect on the splash.

Introduction

The impingement of a liquid jet on a dry surface is of great importance in many industrial applications. Examples are spray-coating and impingement cooling. One interesting application is utilization of liquid friction modifiers (LFM's) in the railroad industry. LFM's are applied on the top surface of the rail through sprays mounted under the locomotives or rail cars [1]. LFM's are water-based suspensions of polymers and inorganic solids showing non-Newtonian behavior [2]. Sprays nozzles are typically air-blast atomizers located 75 mm from the top-of-rail surface. Improved fuel economy and reduced rail and wheel wear are achieved from LFM application. Recent experiments by Dressler et al [3] showed that the air-blast atomizers are not working ideally; in most cases some post-impact liquid ligaments/droplets are carried away from the surface by the atomizing air jet, which leads to a lower transfer efficiency. To avoid this problem the authors developed a new airless, non-atomizing sprayer, which produces a high-speed liquid stream. In contrast with the vast amount of research on droplet interaction with stationary/moving surfaces [3, 4] we know of no previous studies of a high speed Newtonian/non-Newtonian liquid jet impinging on a high speed moving surface. Due to the greater complexity of the non-Newtonian case, this initial study was focused on Newtonian test liquids.

Materials and Methods

Seven different mixtures of water and glycerin were used as the Newtonian test liquids to isolate the shear viscosity effects (Table 1). The viscosity of these mixtures varied by three orders of magnitude. An airless spray nozzle with a diameter equal to 648 μm was used to apply the test fluids to a rapidly moving projectile [3]. The main benefits of the test configuration are that the effect of surface speed can be studied readily and that impingement always occurs on a dry surface. A Phantom V12 video camera operating at 6200 frames per second with a high-intensity halogen lamp light source was used to visualize the jet impingement on the fast moving surface.

Results and Discussion

For all fluids tested, as the jet velocity increases impingement is more likely to be associated with splash than direct deposition. This finding is consistent with the single droplet impingement experiments of Yarin [4]. We also found that impingement transitions from direct deposition to splash while keeping the jet velocity constant but increasing surface speed, Figure 2. This finding prompted the authors to introduce as a parameter the relative jet velocity, (V_{rel}), which is the magnitude of the vector sum of the jet and surface velocities, Figure 1.

Jet impingement on a surface is a function of the relative jet velocity, (V_{rel}), the jet diameter, (D), the impingement angle in the frame of reference of the surface, (α), the fluid density, viscosity, and surface tension, (ρ, μ, σ), and the surface roughness, (ε). These seven variables may be reduced to four dimensionless groups:

$$Re = \frac{\rho V_{rel} D}{\mu} \tag{1}$$

$$We = \frac{\rho {V_{rel}}^2 D}{\sigma} \tag{2}$$

α: Impingement angle in the frame of reference of the surface (3)

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[1] Corresponding author: bavand@interchange.ubc.ca

$\frac{\varepsilon}{D}$: Relative Roughness (4)

The splash/non-splash boundaries for seven Newtonian testing liquids are depicted in Figure 3. It is apparent that the splash/non-splash boundary is more strongly dependent on Re than on We. As seen in Figure 4, the effects of α on the splash are modest relative to the effect of the Reynolds number. The roughness results will be given in the full paper.

Acknowledgement

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Nomenclature

D	diameter[m]	σ	surface tension[N.m^{-1}]
Re	Reynolds Number	ε	Roughness Height [m]
V	velocity[m.s^{-1}]	μ	viscosity[Pa.s]
We	Weber Number	ρ	density[kg.m^{-3}]
α	Jet impingement angle in solid surface frame of reference[rad]	wt	weight

References

[1] J. Cotter et al., *Proc. Of the International Heavy Haul Conference*, 2005, pp. 327-334.
[2] L.K.B. Li et al., *Journal of Atomization and Sprays*, 19:157-190(2009).
[3] D.M. Dressler et al., *Journal of Atomization and Sprays*, 19:19-39(2009).
[4] A.L. Yarin, *Annual Review of Fluid Mechanics*, 38:159-192(2006).

Table 1: The composition and properties of Newtonian test liquids at 25°C [2]

Glycerin[wt%]	Water[wt%]	Viscosity[mPa.s]	Surface Tension[mN/m]	Density[g/cm^3]
0	100	0.9	72.1	1.00
50	50	5.1	68.8	1.13
65	35	12.5	67.5	1.17
75	25	28.0	67.1	1.20
80	20	46.7	66.6	1.21
90	10	154	61.9	1.23
99.5	0.5	806	61.9	1.26

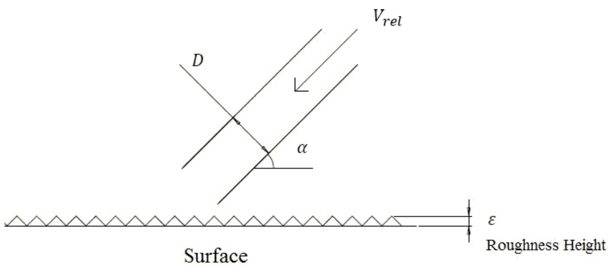

Figure 1. Relative Jet Velocity

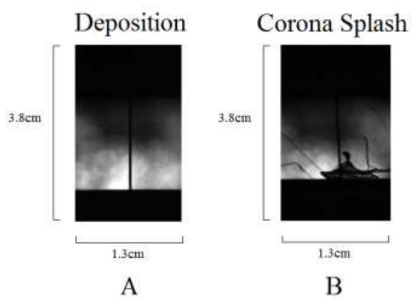

Figure 2. Projectile is traveling from left to right with a velocity equal to 10.8 m/s (A) and 13.9 m/s (B). In both (A) and (B) the jet velocity is 17.5 m/s.

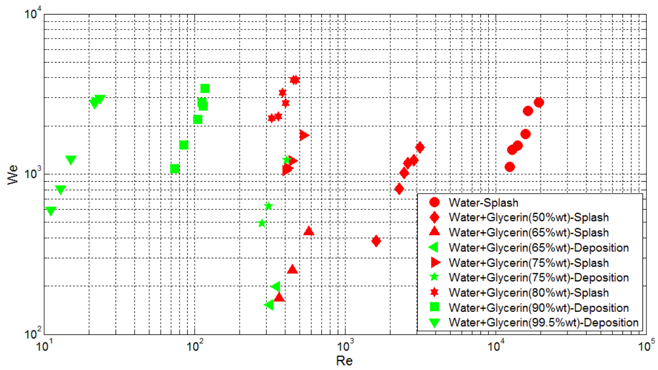

Figure 3. Splash/non-splash boundary.

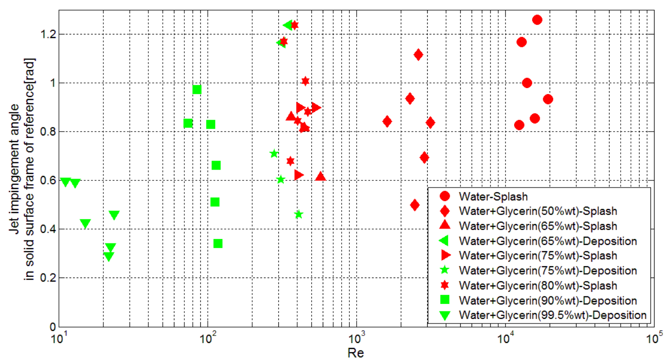

Figure4. Splash/non-splash boundary.